

FREQUENCY-RANGE DISTRIBUTION OF BOULDERS AROUND CONE CRATER: RELEVANCE TO LANDING SITE HAZARD AVOIDANCE. R. N. Clegg-Watkins^{1,2}, B. L. Jolliff¹, S. J. Lawrence³, ¹Washington University in St. Louis and the McDonnell Center for the Space Sciences, Campus Box 1169, 1 Brookings Dr., Saint Louis, MO 63130, rclegg@levee.wustl.edu, ²Planetary Science Institute, Tucson, AZ, ³NASA Johnson Space Center, Houston, TX.

Introduction: Boulders represent a landing hazard that must be addressed in the planning of future landings on the Moon. A boulder under a landing leg can contribute to deck tilt and boulders can damage spacecraft during landing. Using orbital data to characterize boulder populations at locations where landers have safely touched down (Apollo, Luna, Surveyor, and Chang'e-3 sites) is important for determining landing hazard criteria for future missions. Additionally, assessing the distribution of boulders can address broader science issues, e.g., how far craters distribute boulders and how this distribution varies as a function of crater size and age.

The availability of new Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) images [1] enables the use of boulder size- and range-frequency distributions for a variety of purposes [2-6]. Boulders degrade over time and primarily occur around young or fresh craters that are large enough to excavate bedrock. Here we use NAC images to analyze boulder distributions around Cone crater (340 m diameter) at the Apollo 14 site. Cone crater (CC) was selected because it is the largest crater where astronaut surface photography is available for a radial traverse to the rim. Cone crater is young (~29 Ma [7]) relative to the time required to break down boulders [3,8], giving us a data point for boulder range-frequency distributions (BRFDs) as a function of crater age.

Methods: We used CraterTools [9] in ArcMap to visually identify and estimate the size of boulders in an

~7 km² count area centered on Cone Crater (Fig. 1a). CraterTools is designed to count craters, so boulder sizes are recorded in terms of a circular diameter to capture the long dimension. Using NAC images with a resolution of 0.5 m/pixel, the smallest boulders that can be identified with confidence are ~1 m. We then determine the BRFD at increasing distances (in units of crater radii) to find how the frequency of boulders varies as a function of distance from the crater rim.

Boulder Distributions: We counted 2441 boulders, 2011 of which are outside the crater. The boulders range in diameter up to ~8 m, with the majority of large (>4 m) boulders falling within 2 crater radii of the rim. About 25% of the boulders occur on or within 0.5 crater radii of the rim. The quantity (areal density) of boulders decreases with increasing distance from the crater rim (Fig. 1b), with a few clusters around 6-7 crater radii. The distribution is well fit by a power-law function. Only a few boulders occur near the Apollo 14 lander, ~8 crater radii from CC. Few boulders originating from CC are detected beyond 8 crater radii, providing a key data point for the distance that a crater of this size distributes boulders.

Ongoing work includes verifying LROC boulder counts with Apollo 14 surface photography and using LROC data with Diviner rock-abundance data to extrapolate to submeter boulder populations that may also pose a landing hazard. This information, coupled with counts at other spacecraft landing sites and verification using surface photography, can inform boulder populations at varying distances from craters and aid in establishing safe landing zones for future missions [10,11].

References: [1] Robinson et al. (2010) *Space Sci. Rev.* 150, 81–124. [2] De Rosa et al. (2012) *PSS* 74, 224–246. (1997) *JGR* 90, 1151–1154. [3] Basilevsky et al. (2013), *PSS* 89, 118–126. [4] Banfield et al. (2011) *JGR* 116 [5] Lawrence et al. (2013) *JGR* 118, 615–634. [6] Jawin et al. (2014) *JGR-Planets* 119, 2331–2348. [7] Arvidson et al. (1975) *Moon* 13, 259–276. [8] Ghent et al. (2014) *Geology* 42, 1059–1062. [9] Kneissl et al. (2011) *PSS* 59, 1243–1254. [10] Bart and Melosh (2010) *Icarus* 209, 337–357. [11] Cintala and McBride (1995) NASA TM-104804.

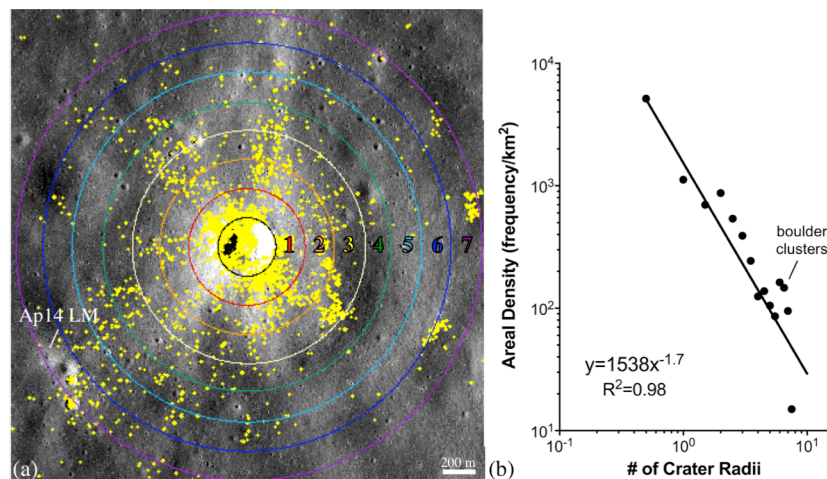


Figure 1: (a) Count area, centered on Cone Crater. Colored circles and numbers indicate distances from the rim (black circle) in crater radii. (b) The frequency of boulders falls off with increasing distance and can be fit with a power-law function.